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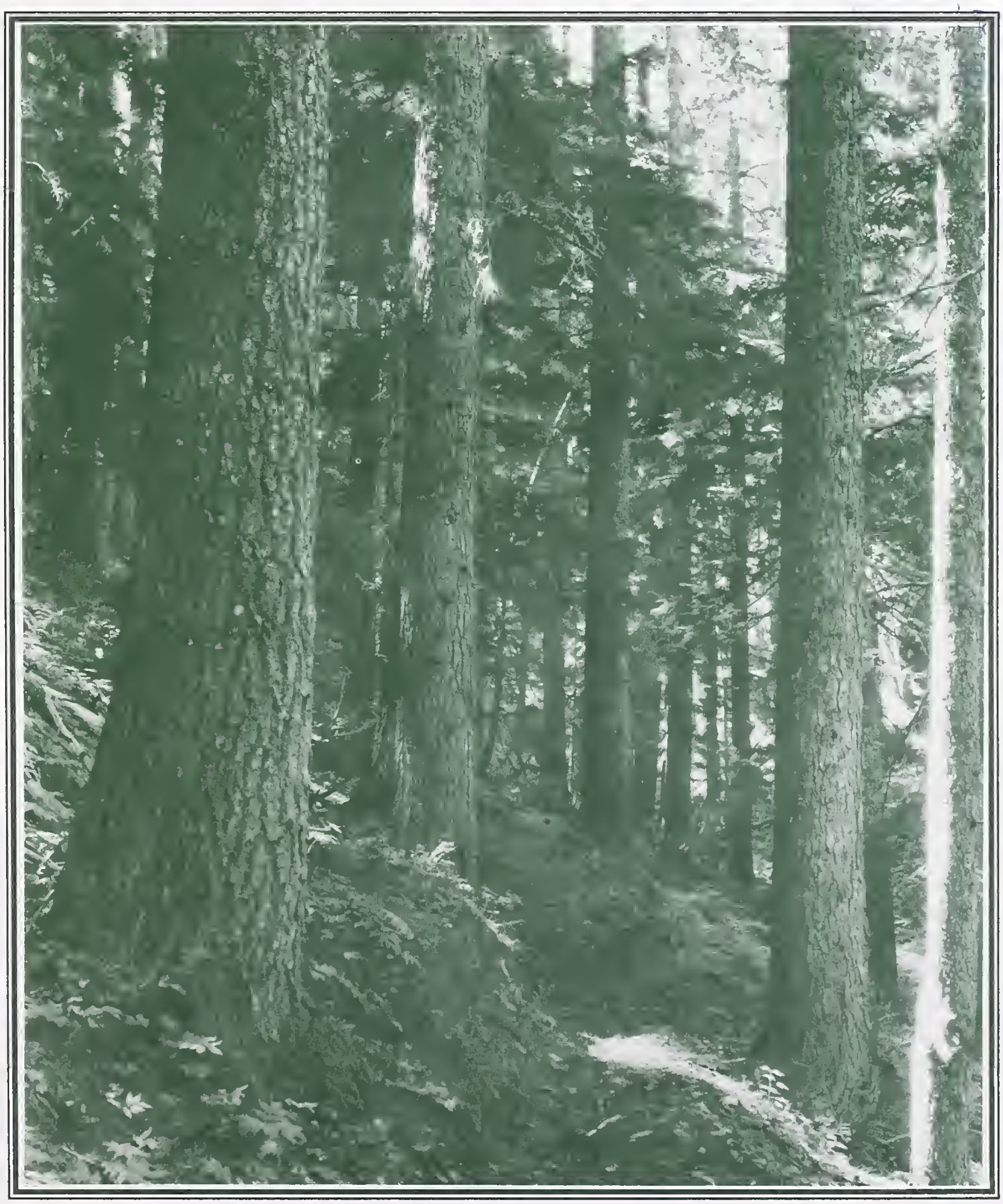
Baseline Demographics of Late Successional Western Hemlock/Western Redcedar Stands in Northern Idaho Research Natural Areas

Melinda Moeur



THE AUTHOR

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RESEARCH SUMMARY

This paper describes data collected from six permanent study plots established in old-growth western hemlock/western redcedar stands. The study sites in the Canyon Creek, Montford Creek, and Tepee Creek Research Natural Areas in the northern Idaho panhandle have suffered no stand-replacing disturbances for more than 200 years. Heavy mortality of western white pine from mountain pine beetle and blister rust has accelerated succession on these sites. The more shade-tolerant hemlock and redcedar have largely replaced the white pine that originally dominated these sites. On each plot, species composition and size distribution are summarized for live canopy trees, dead trees, and regeneration trees. Structural characteristics of the plots are compared on the basis of successional age as measured by relative canopy openness. These data establish a baseline for natural development of old stands on the sampled hemlock habitat types. The permanent plots established in this study will be scheduled for remeasurement every 10 years, providing essential information for baseline monitoring of old-growth hemlock and redcedar forests.

ACKNOWLEDGMENTS

This paper is dedicated to Chuck Wellner for his contributions to the Idaho Natural Areas Committee in establishing Research Natural Areas in the Northern Rocky Mountains. I thank him for passing on to me his appreciation of the ecology of these old-growth forests, and for teaching me about the history of Forest Service research in northern Idaho.

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Cover: *View of dense 200-year old virgin western white pine and hemlock in Montford Creek Natural Area, Deception Creek Experimental Forest, ID, in September 1937. Photo by K. D. Swan (U.S. Forest Service photo).*

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INTRODUCTION

Current interest in the dynamics of late-successional (old-growth) forests arises from their grandeur and esthetic appeal, their ecological complexity, their function as habitat for certain sensitive wildlife species, and their role in timber supply. Remnant stands of old-growth western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western redcedar (*Thuja plicata* Donn ex D. Don) can still be found scattered through the panhandle of northern Idaho, primarily in protected areas.

Our present knowledge of old-growth forest types of the Northern Rocky Mountains is limited. While structural characteristics of second-growth and even-aged stands are fairly well documented, comparative studies in old-growth forests are uncommon. Most studies of old-growth conifer ecosystems have been concentrated in coastal forests of the Pacific Northwest. Those findings are largely inappropriate for inland forests. The study of old-growth can help address issues related to economics, threatened and endangered species, and biodiversity. We need to better understand how future management of old-growth forests and associated ecosystem components will affect social and biological concerns. In October 1989, the Chief of the Forest Service, U.S. Department of Agriculture, issued a position statement and directive to Regional Offices to study old-growth forests as an integrated part of National Forest management. Definitions for old-growth forests were to be developed by ecosystem type and geographic location. Alternatives for maintaining old-growth ecosystems and related values in conjunction with biodiversity were to be compared in light of overall management goals.

This paper describes data collected from six permanent study plots in old-growth stands of western hemlock/western redcedar in three Research Natural Areas in the northern Idaho panhandle. The paper reports current demographics for the old-growth study plots, summarizing the species composition and size distributions of canopy and regeneration trees on each plot. The results presented in this paper are taken from a larger study in which structural relationships between canopy trees and seedlings in old-growth forests were examined (Moeur 1990, Moeur 1991, Moeur in preparation). The larger study was designed to develop spatially sensitive models capable of predicting natural regeneration beneath old-growth canopies.

These data establish a baseline for natural development of old-growth stands on the sampled hemlock habitat types. The permanent plots established in this study will be scheduled for remeasurement every 10 years, providing essential information for baseline monitoring of old-growth hemlock and redcedar forests.

STUDY AREAS

Research Natural Areas (RNA's) are sites set aside as examples of natural ecosystems undisturbed by human influence, designated for scientific and educational purposes (Habeck 1988). The three RNA's in this study—Tepee Creek, Canyon Creek, and Montford Creek—were established more than 50 years ago to provide undisturbed examples of western white pine forest type in advanced stages of succession.

The hemlock/redcedar forests in these RNA's occur in the "white pine zone" of northern Idaho. The area originally had a large component of economically valuable western white pine (*Pinus monticola* Dougl. ex D. Don) (Huberman 1935). White pine was the major seral species, along with varying proportions of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), western larch (*Larix occidentalis* Nutt.), and Engelmann spruce (*Picea engelmannii*

Parry ex Engelm.). Western hemlock or western redcedar were the eventual climax species. These forests usually became established after catastrophic fires (Marshall 1928). On moist hemlock/redcedar sites within this zone, stand-replacing fires occur only every 500 years or longer (Cooper and others 1991). Partly because of fire's relative infrequency, succession has resulted in the gradual replacement of white pine and other seral species by shade-tolerant hemlock and redcedar. The following excerpts from Haig and others (1941) describe the transition from white pine forest to one dominated by hemlock and redcedar:

> Maturity of western white pine stands is reached between 140 and 200 years.... The stand then enters into a long period of maturity marked by the gradual decline of the less tolerant species and the slow ascendancy of the more tolerant.... As the climax type is approached, the less tolerant species do not drop out either regularly or completely, but irregularly and slowly, remaining in the stand as scattered trees for a very long time.... Openings resulting from light fires, blowdowns, or insect and disease attacks are largely filled by the more tolerant species.... Formerly suppressed hemlock, grand fir, and redcedar fill some of the openings, and eventually new reproduction, mostly though not entirely of these very tolerant species, fills other gaps in the stand.... The more intolerant species, including white pine, can neither persist in the form of an understory nor start from seed under dense shade.... There finally results, on the average site, an irregular and uneven-aged forest mainly composed of western hemlock, grand fir, and western redcedar.

The plots described in this study have suffered no catastrophic, stand-replacing disturbances for more than 200 years. Instead, succession has proceeded in the directional manner described by Haig and others (1941), punctuated by insect and pathogen damage, windthrow, and snow breakage affecting individual trees. The last 50 years have brought rapid change, with mountain pine beetle (*Dendroctonus ponderosae*) killing many white pines. White pine blister rust (*Cronartium ribicola*) was introduced to the Inland Empire in the 1920's. It may not have killed many large, old trees outright, but it probably increased their susceptibility to mountain pine beetle. Now the very shade-tolerant hemlock and redcedar have largely replaced the white pine and other seral species that orginally dominated these sites.

METHODS

Six study plots were established within three Research Natural Areas in northern Idaho. The study plots represent a gradient of successional "ages" as measured by relative canopy openness, species composition, and size distributions of canopy and regeneration trees. Two permanent plots were installed in each of three relative canopy conditions: predominantly closed (a relatively complete canopy with almost no distinct canopy gaps, producing partial or complete shade at the forest floor for most of the day), intermediate or gappy (a complete canopy with distinct gaps producing patches of light interspersed with deep shade), and mostly open (scattered crowns within a predominantly open canopy producing high light intensity across the entire site sometime during the day).

Canopy density conditions were delineated on aerial photos of old-growth within each Natural Area. Then, a walk-through reconnaissance of each area was conducted, to stratify the area on the ground. Within canopy density strata, plot locations were chosen randomly, first selecting a random coordinate for the southwest plot corner. The plot was then oriented along the primary slope contour to avoid any obvious environmental gradients.

The two "closed-canopy" plots were placed within the Canyon Creek and Tepee Creek RNA's, the two "gappy-canopied" plots in the Tepee Creek and Montford Creek RNA's, and the "open-canopied" plots in Canyon Creek and Montford Creek. At each of the six study sites, a fixed-area rectangular plot was established, ranging in size from 0.33 to 0.90 acres (table 1). Plot corners were permanently monumented by wooden posts with aluminum tags identifying the study.

Canopy Trees

Two main classes of trees ("canopy" and "regeneration") were distinguished on each plot. Canopy trees were defined as those trees at least 3 inches in diameter breast height (d.b.h.). They included dead trees, either standing or down, estimated to have been at least 3 inches d.b.h. at death. Species, d.b.h. to nearest 0.1 inch, and crown ratio (ratio of live crown length to total height, to nearest 10 percent) were recorded for every live canopy tree on a plot. Increment cores were extracted from six to eight of the largest trees per plot. Annual rings were counted to estimate plot age. All live canopy trees were permanently tagged at breast height with numbered aluminum tags.

Total height and crown width were measured on about 10 percent of live canopy trees, by species. The subsample was distributed uniformly across 5-inch diameter classes. Tree height was determined by the pole-tangent method (Curtis and Bruce 1968). Crown width was measured as the average diameter of the crown projection area in two perpendicular directions. Crown projection was estimated from the ground by taking a vertical sighting to

Table 1—Site attributes of the six northern Idaho old-growth study plots

	Canyon Creek plot 1	Canyon Creek plot 2	Montford Creek plot 1	Montford Creek plot 2	Tepee Creek plot 1	Tepee Creek plot 2
Area (acres)[1]	0.44	0.42	0.51	0.33	0.90	0.52
Slope (percent)	40	40	0	60	0	0
Aspect	N	NNE	LEVEL	NNE	LEVEL	LEVEL
Elevation (feet)	4,600	4,550	3,000	4,150	2,720	2,760
Canopy	Closed	Open	Gappy	Open	Gappy	Closed
Age (years)[2]	310	500	210	240	280	270
Habitat type[3]	TSHE/CLUN/ XETE	TSHE/MEFE	TSHE/ATFI	TSHE/GYDR	TSHE/CLUN/ ARNU	TSHE/CLUN/ CLUN

[1]All plot areas are expressed as horizontal area after correction for slope distance.
[2]From subsample of ages of largest diameter trees.
[3]TSHE = *Tsuga heterophylla;* CLUN = *Clintonia uniflora*; XETE = *Xerophyllum tenax*; MEFE = *Menziesia ferruginea*; AFTI = *Athyrium filix-femina*; GYDR = *Gymnocarpium dryopteris*; ARNU = *Aralia nudicaulis.*

crown dripline with a clinometer. The subsample was used to refit equations developed in previous work for predicting tree height and crown width. These equations were used to estimate tree height and crown width for every live canopy tree on the plot. Total tree height was estimated from d.b.h. and species for all canopy trees using a height-diameter model from Wykoff and others (1982). Parameters of the equation were estimated from the subsampled trees for each plot separately. The form of this function is

$$\ln(height) = c_0 + \frac{c_1}{d.b.h. + 1} + 4.5$$

where c_0 and c_1 are species-dependent coefficients. Similarly, crown diameters were predicted for all canopy trees using a species-specific regression equation (Moeur 1981) refit to the subsampled data. The crown width equation was of the form

$$\ln(crown\ width) = c_0 + c_1 \ln(d.b.h.) + c_2 \ln(height) + c_3 \ln(crown\ length)$$

where c_0 and c_2 are species-specific coefficents, and c_1 and c_3 apply to all species.

Dead tree height was recorded to the nearest foot. Dead tree condition was recorded as standing, snag or snapped, stump or rootmound, or windthrown. Breast height diameter was measured to the nearest inch on sound dead trees, whether standing or down. Where advanced decay of the bole made diameter breast height impossible to measure on down dead trees, stump diameter was estimated to the nearest inch. When possible, the species of dead tree was identified.

The locations of all live and dead trees 3 inches or more d.b.h. were mapped on each study plot. This information was used in the larger study to examine the spatial patterns of canopy and regeneration trees in these old-growth stands (Moeur 1991). A lightweight transit mounted on a tripod and an electronic distance-measuring instrument were used to measure angles and distances to each tree from a known reference point. These measurements were converted to a Cartesian coordinate system, so that all tree locations as (x, y) coordinates relative to an origin centered on the southwest corner. Mapping procedure details are in documents describing the larger study (Moeur 1991, in preparation).

Regeneration Trees

Regeneration was defined as any live tree less than 3 inches d.b.h. and at least 0.5 feet in height for shade-tolerant species such as subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), redcedar, grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.), hemlock, and Pacific yew (*Taxus brevifolia* Nutt.), or 1 foot for shade-intolerant species such as Douglas-fir, white pine, and Rocky Mountain maple (*Acer glabrum* Torr.). Whereas all canopy trees on each plot were measured, it was impossible to record all regeneration trees. Instead, a two-stage design was used to sample regeneration on each site.

Each plot was subdivided into 25 adjacent rectangular sections that did not overlap. The sections were delineated by string stretched between wooden stakes planted at grid points. In the first sample stage, regeneration species composition, height class, and density class were recorded over the entire plot in the following manner. Each of the 25 sections of the gridded plot was visually divided into 16 adjacent, nonoverlapping quadrats. For each quadrat, density class was recorded, along with species and height class of the **best tree** (the largest, most vigorous regeneration tree in the quadrat—see Ferguson and Crookston 1991), chosen because it would most likely become the "gap filler" (in the sense of Hibbs 1982) during subsequent stand development. Density class was recorded as 0, 1, 5, 10, or

100 regeneration trees in a quadrat, and height class of the best tree as 0-3, 3-6, 6-10, or more than 10 feet.

In the second stage, a stratified random sample of the first-stage quadrats was drawn on which individual regeneration trees were tallied. Sampling intensity was proportional to the occurrence of the different classes across the whole study plot, with the goal of sampling at least 10 percent of each combination of density/species/height class. Species and height to the nearest foot were recorded for every regeneration tree in the second-stage sample. Regeneration tree locations were recorded for use in the larger study, as described in Moeur (1991). Estimates of trees per acre by species were calculated from the two-stage stratified random sample.

RESULTS

Site attributes and demographic summaries of the old-growth plots are described next. The current successional status of each plot is discussed, recognizing that selected sites are not intended to represent an orderly chronosequence. Rather, differences between plots reflect unknown disturbance histories, random regeneration events, and environmental heterogeneity.

Figure 1—The northern Idaho old-growth study areas.

The Canyon Creek Plots

The Canyon Creek RNA is located in the southeast corner of the Priest River Experimental Forest in the Kaniksu National Forest in Bonner County, ID (Sections 20, 21, 28, 29, and 30, T58N, R3W, Boise Meridian) (fig. 1). The Research Natural Area was established in 1937 to preserve upper elevational examples of the white pine type in late succession. A description of the natural area can be found in the Canyon Creek RNA Establishment Record (Wellner 1984). The 982-acre area encompasses the upper slopes of Gisborne Mountain, at elevations from 4,150 to 5,970 ft. Stands dominated by western hemlock and/or western redcedar cover about one-third of the RNA. Soils are derived from underlying Precambrian Belt rock with overlying loess and volcanic ash. They have been described as Jughandle silt loam, moderately well drained (Wellner 1984). Annual precipitation is about 50 inches, falling mainly from November through January, building snowpacks of up to 15 feet. Summers are typically hot and dry. Mean annual, minimum, and maximum temperatures are 44, 17, and 83 °F.

The two Canyon Creek study plots were established on *Tsuga heterophylla/Clintonia uniflora/Xerophyllum tenax* and *Tsuga heterophylla/Menziesia ferruginea* habitat types, the driest of the hemlock types (habitat type nomenclature follows Cooper and others 1991). Both are on north-facing, moderately steep slopes. They are the oldest of the study sites, with some large trees 310 to more than 500 years old (table 1).

Canyon Creek RNA, Plot 1—Plot 1 in Canyon Creek (closed-canopy) is on a 40 percent slope, northerly aspect, at 4,600 feet elevation (table 1). The generally single-storied, closed canopy produces a uniformly low light climate at the forest floor level (fig. 2a). Except for a few discrete patches of *Vaccinium* spp. and *Xerophyllum tenax* beneath light gaps, the understory is generally depauperate of shrubs and herbs. Conifer regeneration is extremely sparse (fig. 2b).

Medium-diameter hemlock and smaller hemlock and redcedar make up most of the 122 live canopy trees per acre (table 2). The hemlock has a unimodal diameter class distribution with trees in all but the largest size class (fig. 2c). The largest diameter hemlocks are about 220 to 250 years old. The redcedar trees on plot 1 are about 90 years old, occupying only the two smallest size classes. One large live white pine, around 310 years old, is on the plot.

Crown cover is concentrated in the upper canopy trees (fig. 2d). The percentage crown cover was computed as the ratio of the crown projection areas

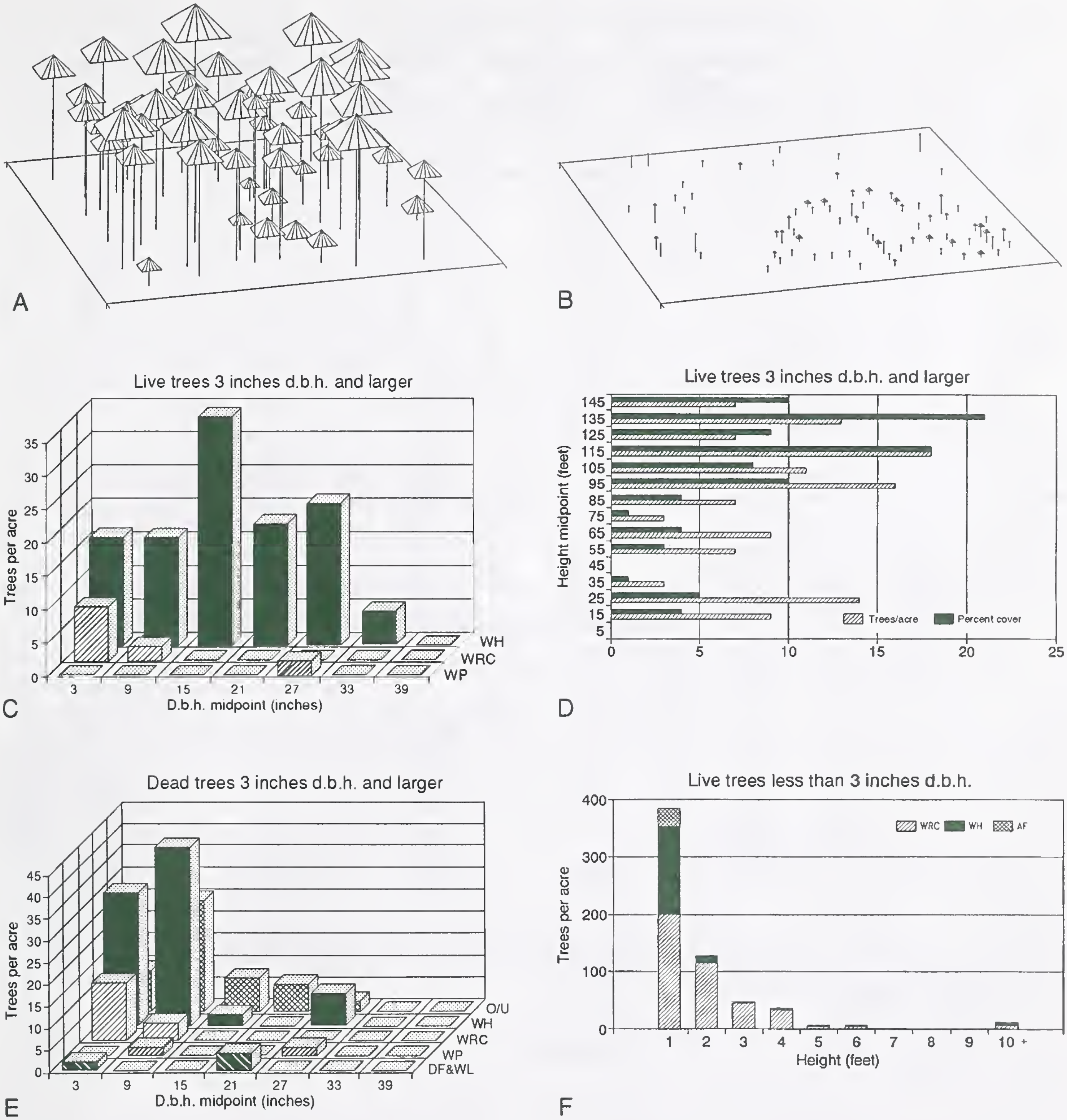

Figure 2—Tree distributions on Canyon Creek plot 1 (closed canopy). (A) Three-dimensional representation of the live overstory, showing mapped locations of trees. Symbol heights and widths are proportional to tree heights and crown diameters. (B) Mapped representation of regeneration trees from the first stage sample. Symbol widths are proportional to density class in the quadrat, and symbol heights are proportional to height of the crop tree in the quadrat. (C) Diameter distribution, live canopy trees. (D) Canopy cover and trees per acre by height class. (E) Diameter distribution, dead canopy trees. (F) Regeneration height distribution.

Species abbreviations: **AF** = subalpine fir, **WRC** = western redcedar, **DF** = Douglas-fir, **GF** = grand fir, **Other** = (paper birch, black cottonwood, and Engelmann spruce), **O/U** = Other/Unknown, **RM** = Rocky Mountain maple, **WH** = western hemlock, **WL** = western larch, **WP** = western white pine, and **Y** = Pacific yew.

Table 2—Species composition of the six northern Idaho old-growth study plots

Species[1]	Canyon Creek plot 1 Closed canopy tpa[2]	ba[3]	Canyon Creek plot 2 Open canopy tpa	ba	Montford Creek plot 1 Gappy canopy tpa	ba	Montford Creek plot 2 Open canopy tpa	ba	Tepee Creek plot 1 Gappy canopy tpa	ba	Tepee Creek plot 2 Closed canopy tpa	ba
Live trees ≥ 3 inches d.b.h.												
DF&WL	0	0	2	5	0	0	0	0	0	0	2	7
GF	0	0	0	0	0	0	0	0	0	0	6	1
WH	109	198	197	283	84	75	118	287	170	169	165	152
WP	2	9	8	53	10	25	3	19	0	0	2	6
WRC	11	3	87	6	0	0	0	0	48	118	46	99
Y	0	0	0	0	0	0	6	0	8	1	0	0
Other	0	0	0	0	0	0	15	1	2	14	0	0
Total	122	210	294	347	94	100	142	307	228	302	221	265
Dead trees ≥ 3 inches d.b.h.[4]												
DF&WL	6	12	0	0	0	0	0	0	1	3	2	2
GF	0	0	0	0	0	0	0	0	0	0	2	0
WH	81	53	85	153	41	32	82	132	52	104	134	78
WP	4	11	22	51	251	396	15	77	8	14	10	22
WRC	18	3	4	1	0	0	0	0	15	17	12	3
Other	6	4	0	0	0	0	0	0	1	0	0	0
Unknown	43	42	0	0	0	0	0	0	7	11	2	1
Total	160	125	111	205	292	428	97	209	84	149	161	105
Live trees < 3 inches d.b.h.[5]												
	tpa	ht	tpa	ht	tpa	ht	tpa	ht	tpa	ht	tpa	ht
AF	32	1.0	17	5.0	0	—	0	—	0	—	0	—
DF	0	—	0	—	8	1.0	0	—	0	—	0	—
GF	0	—	0	—	1,665	1.7	6,508	1.2	668	1.2	53	1.0
RM	0	—	0	—	0	—	469	3.4	0	—	0	—
WH	172	1.5	1,087	4.4	2,050	1.7	4,445	1.3	9,770	1.4	1,348	1.9
WP	0	—	0	—	0	—	35	1.0	100	1.1	0	—
WRC	413	2.0	4,889	4.6	0	—	0	—	655	3.4	217	2.2
Y	0	—	0	—	0	—	881	3.7	556	3.0	134	1.3
Total	617		5,993		3,723		12,338		11,749		1,752	
(Std. error)	(58)		(372)		(461)		(2,054)		(1,737)		(247)	

[1]Species abbreviations: AF = subalpine fir, DF = Douglas-fir, GF = grand fir, RM = Rocky Mountain maple, WL = western larch, WH = western hemlock, WP = western white pine, WRC = western redcedar, Y = Pacific yew, Other = (paper birch [*Betula papyrifera*], black cottonwood [*Populus trichocarpa*], Engelmann spruce, Pacific yew, Rocky Mountain maple).

[2]tpa = trees per acre computed from complete census.

[3]ba = basal area (feet^2/acre).

[4]Basal area based on estimated d.b.h. or diameter of stump.

[5]The number of trees is based on a stratified random sample estimate calculated from two-stage sample with the mean height calculated from the second-stage sample.

summed over all trees in a height class to plot area times 100. There are no gaps in the distribution of crown cover for the uppermost height classes. This reflects the single-storied nature of the canopy on plot 1.

Plot 1 has 160 dead trees per acre (table 2), most of which are still standing or snapped. Almost all the seral species (white pine, Douglas-fir, western larch, and spruce) have died (fig. 2e). Many hemlock and redcedar less than 12 inches in diameter also have died. Since mortality is concentrated in the smaller shade-tolerant trees, suppression mortality of trees beneath the main canopy is still occurring.

Very sparse conifer regeneration (617 trees/acre) is concentrated in patches beneath one or two canopy openings (table 2). These trees are 67 percent redcedar, with 28 percent hemlock, and some scattered subalpine fir. The majority of regeneration trees are in the 1-foot height class, with redcedar ranging from 1 to 6 feet, and hemlock generally less than 3 feet in height (fig. 2f).

Canyon Creek RNA, Plot 2—Plot 2 in Canyon Creek (open canopy) is on a 40 percent slope facing north-northeast at 4,550 feet elevation (table 1). The overstory consists of large-crowned trees scattered in an open matrix, creating a high light climate throughout the stand (fig. 3a). A second story of redcedar and hemlock regeneration uniformly covers the plot (fig. 3b). Sparse clumps of *Vaccinium* spp. and *Xerophyllum tenax* are the main understory species. Otherwise, few shrubs or herbs are present.

The overstory has 294 live trees per acre, mainly large-diameter hemlock and some smaller hemlock and redcedar (table 2). Two large live white pines and one large Douglas-fir are present. Beneath the upper hemlock canopy is a distinct second canopy of hemlock and redcedar in the 3-inch diameter class. It makes up the majority of the trees on this plot (fig. 3c). The second-generation redcedar and hemlock are about 75 to 85 years old. The old white pine, Douglas-fir, and hemlock are 450 to 500 years old. They apparently became established and developed concurrently. The distribution of percentage crown cover is bimodal, reflecting the distinctly two-storied canopy (fig. 3d). Cover is concentrated in the mid- to upper canopy, and also in the younger hemlock and redcedar. The cover distribution has a large gap in the uppermost canopy (120 to 140 feet), contributing to the open nature of the stand.

No large redcedars are present. But since a large proportion of the trees on the plot are redcedars, the species is likely to be codominant with hemlock in the future. Redcedar on this stand developed after hemlock, a departure from the typical successional pattern on a hemlock habitat type where redcedar would ordinarily be seral to the more shade-tolerant hemlock. This may be explained by the coincidence of one or more prolific seed years, coupled with favorable climatic and soil moisture conditions, to produce a single successful cohort. Mature redcedars in a stand just 200 yards away could have served as a seed source.

The 111 dead trees per acre consist mainly of large white pine (mostly standing) and hemlock (mostly down) (table 2). Mortality is concentrated in the 9- to 27-inch diameter classes, with very little mortality among the younger hemlock and redcedar cohort (those in the 3-inch diameter class) (fig. 3e).

Redcedar comprises 82 percent, and hemlock 18 percent of a fairly dense, uniform regeneration layer (5,993 trees/acre) (table 2). The proportion of redcedar to hemlock is almost 6 to 1. Even though hemlock is the so-called "climax" species on this plot, it is questionable whether hemlock will dominate this site in the long-term absence of disturbance. The regeneration height distribution for this plot differs from the others, with trees in all size classes from 1 to more than 10 feet (fig. 3f).

The Montford Creek Plots

The Montford Creek RNA is within the Deception Creek Experimental Forest, Coeur d'Alene National Forest, in Kootenai County, ID (Sections 30 and 31, T51N, R1W, Boise Meridian) (fig. 1). The Research Natural Area was established in 1937 to provide an undisturbed, old-growth forest of the western white pine type (Wellner 1985). Its 292 acres, ranging in elevation from 3,050 to 4,400 feet, encompass a steep, north-facing drainage typical of the mountainous Coeur d'Alene National Forest. Soils are derived from underlying metasedimentary rocks of the Belt Supergroup with overlying layers of loess and ash (Wellner 1985). From 1936 to 1945, the Deception Creek Experimental Forest recorded the greatest precipitation of any weather station in Idaho, with mean, minimum, and maximum annual precipitation of 52, 37, and 69 inches, respectively. Temperatures are similar to Canyon Creek, except that July and August are the only distinctly summer months.

Montford Creek has the youngest stands of the three study areas, with trees no older than about 210 to 240 years (table 1). The two study plots are on very moist to moist hemlock habitat types (*Tsuga heterophylla/Athyrium filix-femina* and *Tsuga heterophylla/Gymnocarpium dryopteris*).

Montford Creek RNA, Plot 1—Plot 1 in Montford Creek (gappy canopy), on the wettest hemlock habitat type, is at the very bottom of the drainage on a level site at 3,000 feet elevation (table 1). Although some dispute whether this site should be classified as redcedar or hemlock habitat type (Cooper and others [1991] group the incidental *Tsuga heterophylla/Athyrium filix-femina* within *Thuja plicata/Athyrium filix-femina*), it clearly is a site that will continue to be dominated by hemlock, with no redcedar present in the drainage. The canopy is generally closed, with several distinct canopy gaps (fig. 4a). Abundant regeneration is patchy and concentrated beneath the canopy gaps (fig. 4b).

Despite being the youngest of the study sites, plot 1 in Montford Creek has undergone a recent transition from a forest dominated by white pine to a forest dominated by hemlock and grand fir. Mountain pine beetle infestations culminating in the 1960's and 1970's and a white pine blister rust wave year in 1940 have combined to kill nearly all the white pine in the stand. With these agents acting on a larger original component of white pine than on the other study sites, the resulting change in species dominance has been rapid and dramatic. The overstory has only 94 live trees per acre, consisting of small- to medium-diameter hemlock and a few white pines that are barely surviving (table 2). Montford

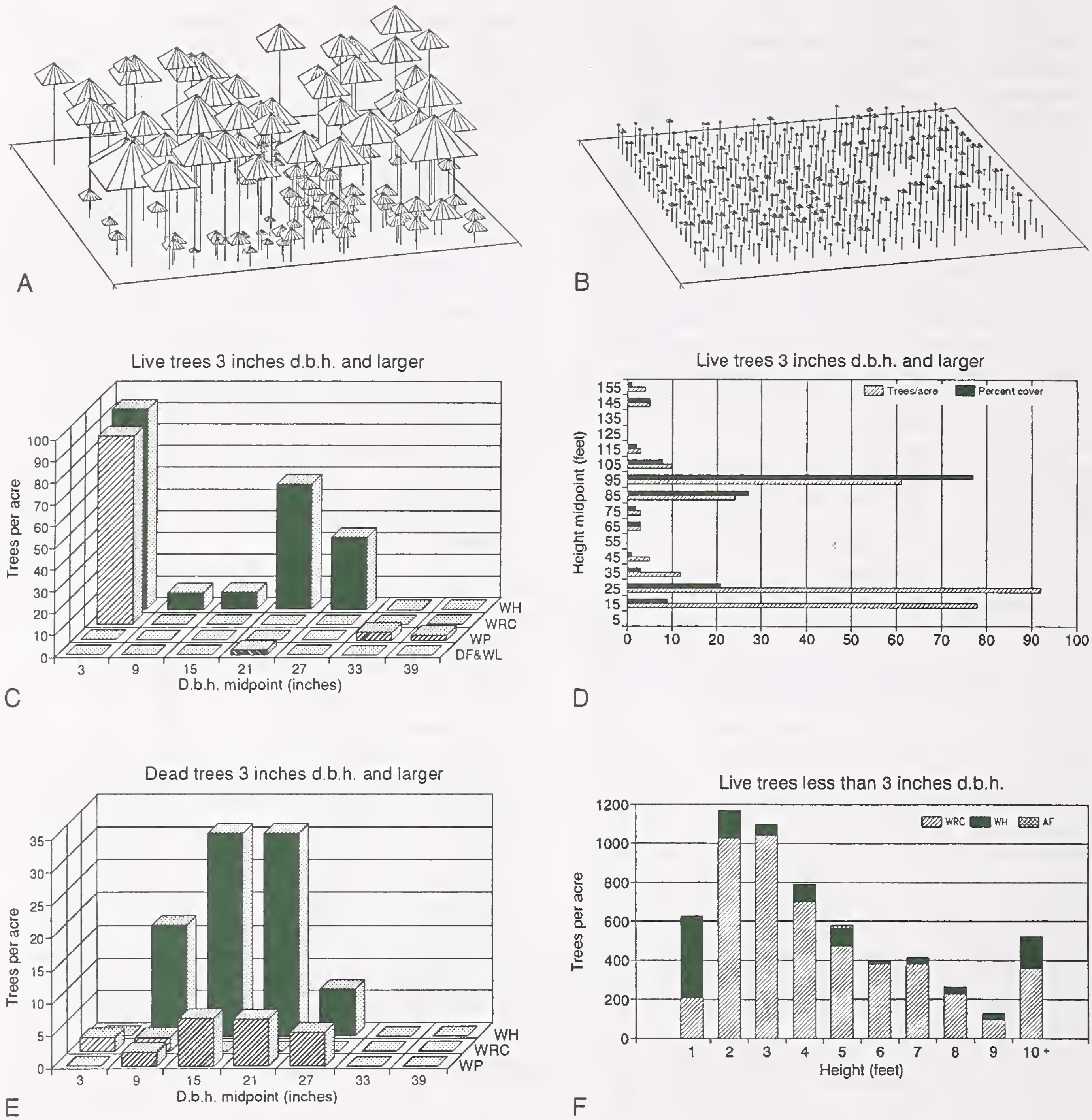

Figure 3—Tree distributions on Canyon Creek plot 2 (open canopy). (A) Map of canopy trees. (B) Map of regeneration. (C) Diameter distribution, live canopy trees. (D) Canopy cover and trees per acre by height class. (E) Diameter distribution, dead canopy trees. (F) Regeneration height distribution. See figure 2 for species abbreviations.

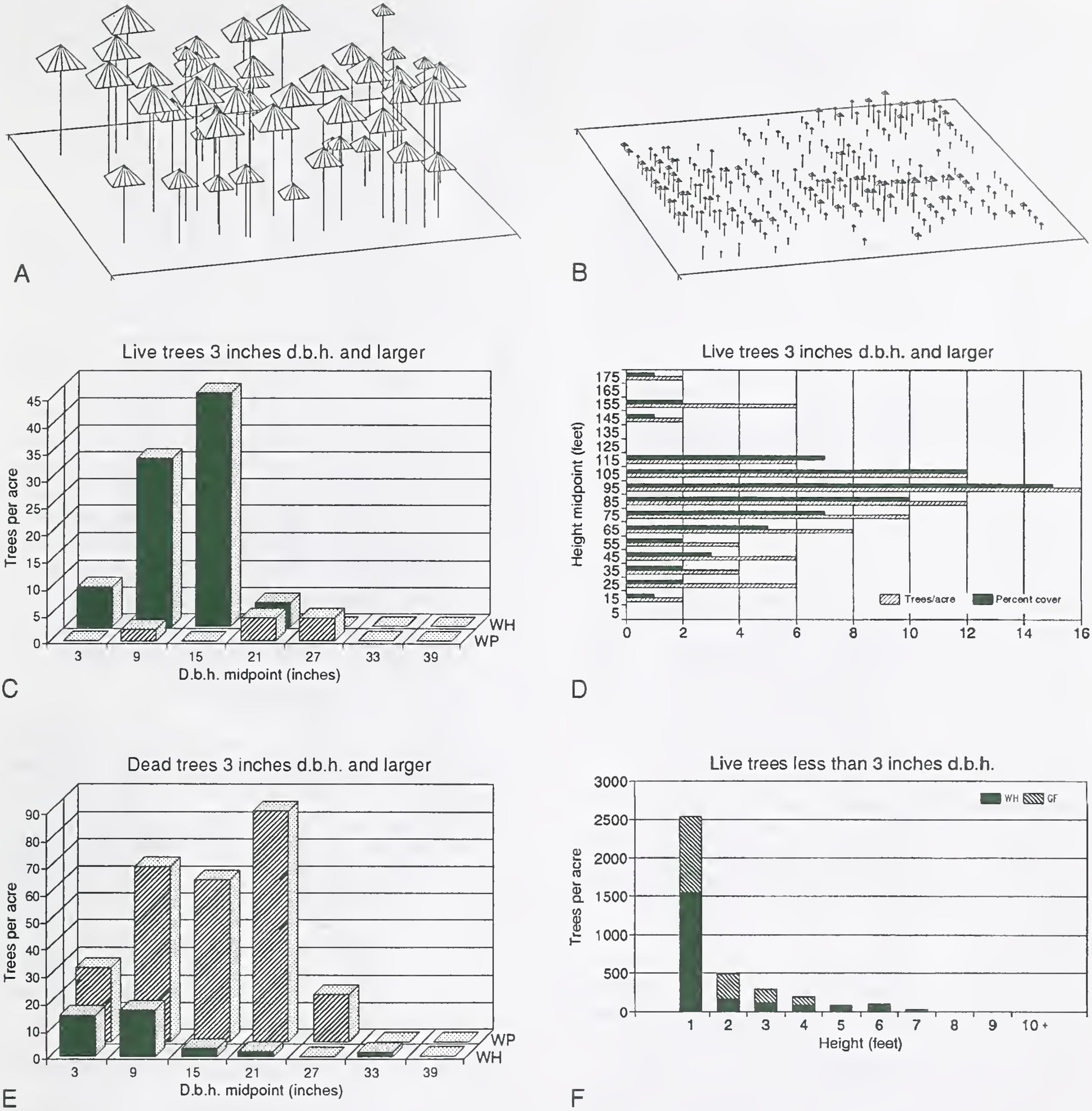

Figure 4—Tree distributions on Montford Creek plot 1 (gappy canopy). See figure 2 for species abbreviations.

Creek plot 1 is unique, experiencing selective sanitation/salvage harvest of several large beetle-killed white pine trees in the 1950's (Boyd, 1992). This cut may have opened the stand enough to allow hemlock to be released, as indicated by a unimodal, even-aged distribution of small- to medium-diameter trees (fig. 4c). The 200-year-old white pines have died or are dying, allowing the population of 100-year-old hemlocks to claim dominance. Cores from several dominant hemlocks show a distinct growth release response in the last 20 years as the white pine have gone out. The crown cover distribution of canopy trees also is unimodal (fig. 4d), reflecting the single-storied overstory. Gaps in the cover distribution between the largest and intermediate height classes represent the gap between the mid-canopy hemlocks and the few large surviving white pine trees.

The stand's most striking feature is the amount of dead white pine (251 dead white pine trees of the 292 dead trees per acre—table 2, fig 4e). Present volumes of 7,600 board feet of live white pine, 11,000 of live hemlock, and 60,000 of standing dead white pine contrast dramatically with an inventory of 99,000 board feet of live white pine and 3,000 of hemlock in the 1960's (Boyd 1992).

Fairly dense regeneration (3,723 trees/acre) on the plot is comprised of 55 percent hemlock and 45 percent grand fir (table 2). Both species are doing quite well. A very few Douglas-fir seedlings are present on the plot. As on all other study plots except Canyon Creek plot 2, the regeneration height distribution is drastically skewed toward trees in the 1-foot height class (fig. 4f). Vigorous hemlock and grand fir saplings are also present. Regeneration is patchy, concentrated beneath canopy gaps or on nurse logs. Herbaceous cover is fairly heavy, especially ferns (*Athyrium filix-femina* and *Gymnocarpium dryopteris*).

Montford Creek RNA, Plot 2—Plot 2 in Montford Creek (open canopy) is on the upper slope of the drainage, on a steep (60 percent) north-northeast-facing slope at 4,150 feet elevation (table 1). The canopy is very open, creating a uniformly high light climate throughout the stand (fig. 5a). Regeneration is abundant and well established, although patchy (fig. 5b).

The overstory (142 trees/acre) is comprised primarily of hemlock from 12 to 36 inches in diameter (table 2). A second generation of hemlock has become established beneath the residual canopy of large scattered hemlock, resulting in an exaggerated bimodal diameter distribution (fig. 5c). One large living white pine is on the plot. The mature hemlocks developed about 40 years after the 240-year-old white pine. Pacific yew (to 3 inches d.b.h.) and Rocky Mountain maple (to 30 feet in height) are both abundant. The bimodal pattern of the canopy coverage distribution (fig. 5d) reflects the diameter class distribution. Most of the canopy cover is concentrated in the larger hemlocks. The lower part of the distribution represents the heavy maple and yew cover.

The 97 dead trees per acre include large standing white pine and medium to large down hemlock (fig. 5e). There is virtually no mortality among hemlocks in the 3-inch diameter class.

Along with yew and maple, *Vaccinium* spp., *Pachistima myrsinites*, and *Menziesia ferruginea* occur in dense patches, providing formidable competition to conifer regeneration. Even so, regeneration is extremely abundant (more than 12,000 trees/acre) (table 2), ranging from 6 inches to more than 10 feet in height. The regeneration is patchy, apparently absent from areas of heavy shrub, maple, and yew competition. Grand fir regeneration is more abundant (53 percent) than hemlock (36 percent), but the more shade-tolerant, longer-lived hemlock should eventually prevail. The height distribution of regeneration on plot 2 resembles the other study plots, with trees concentrated in the 1-foot height class (fig. 5f). Well-established cohorts of hemlock and grand fir regeneration on this site will soon reach the 3-inch diameter class.

The Tepee Creek Plots

The Tepee Creek RNA is located just west of the northwest side of Lower Priest Lake, within sections 16 and 17, T62N, R4W, Boise Meridian, in the Kaniksu National Forest in Bonner County, ID (Davis 1935) (fig. 1). The Research Natural Area is a virtual island of climax forest within an otherwise largely cutover area of extremely productive forests. The 746-acre RNA is at 2,450 to 3,200 feet of elevation, encompassing a moderately flat valley of low ridges and benches cut by streams. Soils are mostly deep sandy loam overlying schistose rock. The nearest available weather records are from the Priest River Experimental Forest some 26 miles to the south. The climate is inferred to be similar to Canyon Creek. In 1935, the cover type of half of the area was described as climax stands about 300 years old, with heavy representations of white pine, hemlock, and redcedar. Today, virtually no live white pine remains on the study plots.

The two Tepee Creek study plots are on fairly moist to moderately dry *Tsuga heterophylla/Clintonia uniflora/Aralia nudicaulis* and *Tsuga heterophylla/Clintonia uniflora/Clintonia uniflora* habitat types. Stands in Tepee Creek are about 270 to 280 years old (table 1), intermediate in age between stands in the other two study areas.

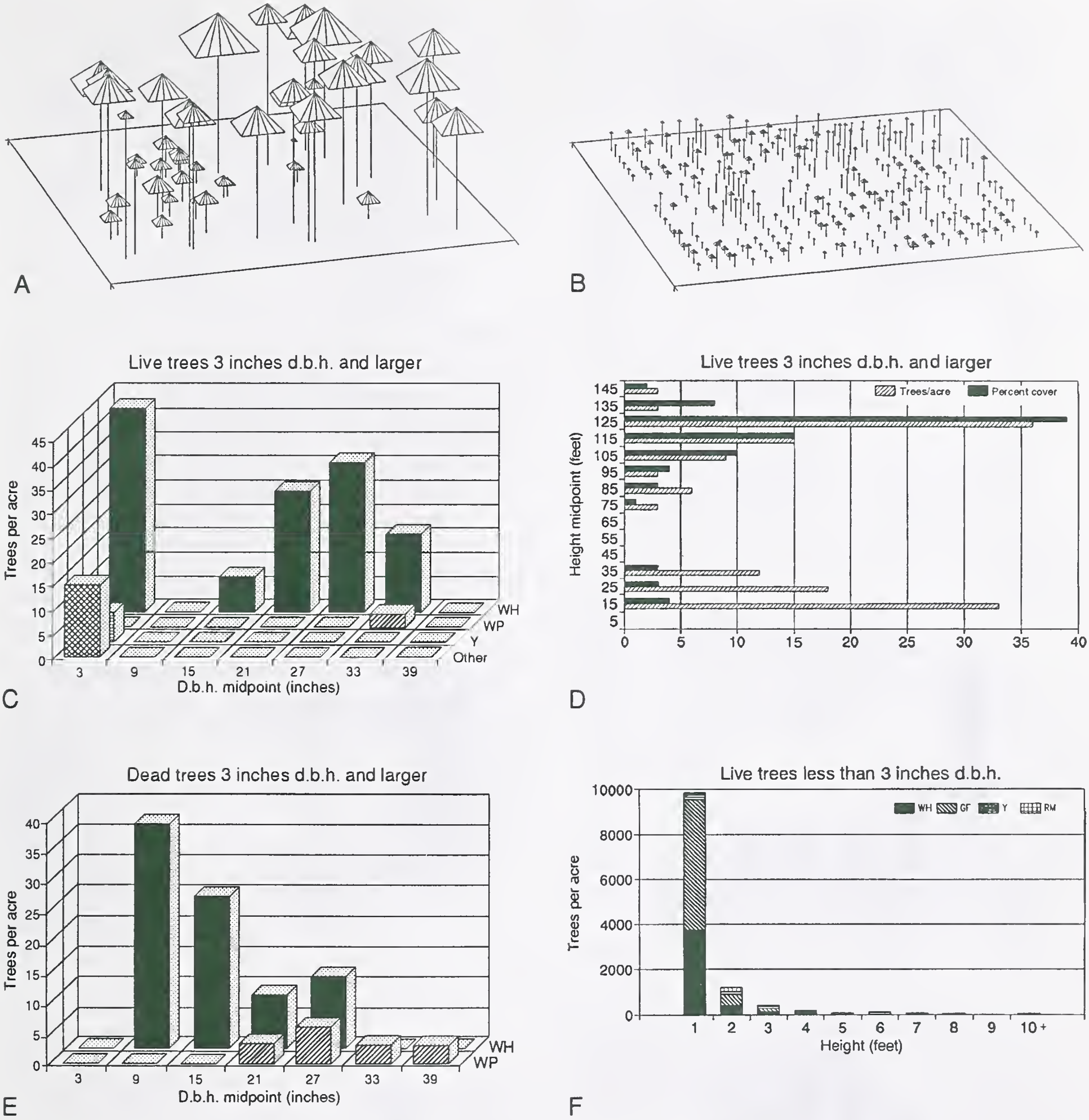

Figure 5—Tree distributions on Montford Creek plot 2 (open canopy). See figure 2 for species abbreviations.

Tepee Creek RNA, Plot 1—Plot 1 in Tepee Creek (gappy canopy) is on a flat bench at 2,720 feet elevation (table 1). The canopy is multistoried and patchy (fig. 6a). Below small and large patches of light are interspersed with areas of deep shade. The forest floor has patches of sphagnum moss and a fair cover of shrubs and forbs common to the *Tsuga heterophylla/Clintonia uniflora* habitat types. Regeneration is abundant across the plot (fig. 6b).

The 228 live canopy trees per acre are comprised mainly of small- to large-diameter hemlock and redcedar, with a midcanopy of Pacific yew up to 6 inches d.b.h. (table 2). The plot contains one 48-inch d.b.h. black cottonwood. Bimodal diameter distributions

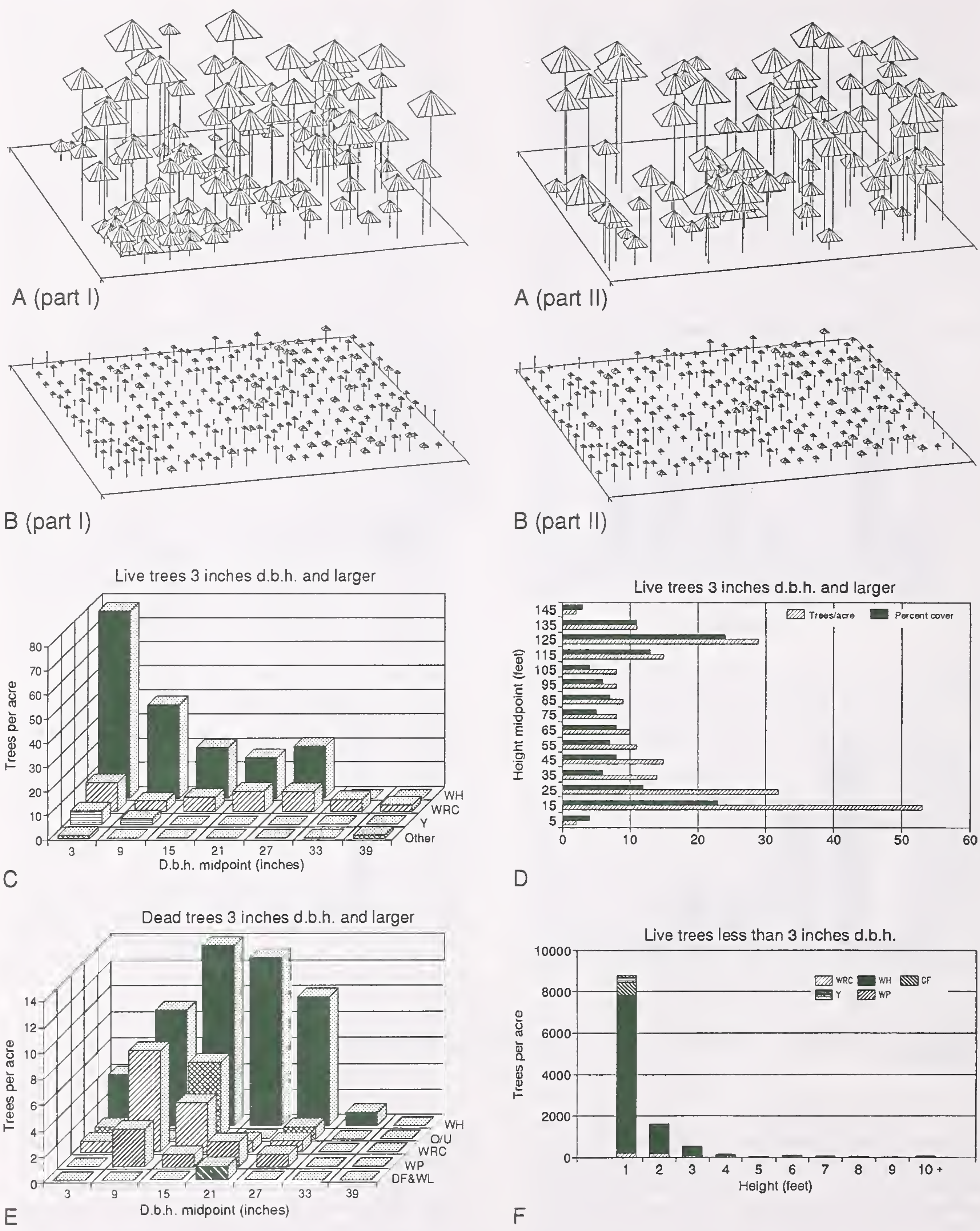

Figure 6—Tree distributions on Tepee Creek plot 1 (gappy canopy). (A) Map of canopy trees for the west half (part I) and east half (part II) of Tepee Creek plot 1. (B) Map of regeneration for the west half (part I) and east half (part II) of Tepee Creek plot 1. See figure 2 for species abbreviations.

for both hemlock and redcedar indicate advance regeneration of these species was recruited into the canopy after the original population became established (fig. 6c). Larger redcedar and hemlock trees on the plot are about the same age, 200 to 220 years. Canopy cover reflects the d.b.h. distribution. Percentage cover has a bimodal distribution, concentrated from 110 to 140 feet and also from 10 to 30 feet (fig. 6d). The bottom portion of the canopy cover distribution reflects the advanced development of smaller trees in patches beneath large canopy gaps (see fig. 6a).

The plot has 84 dead trees per acre (table 2), concentrated in medium- to large-diameter trees (fig. 6e). The smallest diameter classes have experienced much less mortality than in the closed-canopy plots, indicating that suppression plays a less important role on this gappy-canopied plot. All of the white pine, and most of the other seral tree species, have died. Fallen dead trees (large white pine, and small to large hemlock and redcedar) and associated rootmounds are abundant, providing rooting sites for the very dense conifer regeneration (more than 11,000 trees/acre). The regeneration is 83 percent hemlock, with 5 to 6 percent each redcedar, grand fir, and yew (table 2). These trees are from 6 inches to more than 10 feet in height. The height distribution for regeneration trees is drastically skewed toward trees in the 1-foot height class (fig. 6f). Although literally thousands of 6-inch seedlings have rooted on nurse logs, rootmounds, and other "safe sites," most are not likely to survive to maturity. Some white pines, all in the 1-foot height class, have regenerated, but it is doubtful whether these trees will survive.

Tepee Creek RNA, Plot 2—Plot 2 in Tepee Creek (closed canopy) is on a level bench at 2,760 feet elevation (table 1). The canopy is mostly closed, resulting in a uniformly low light climate throughout the stand (fig. 7a). The forest floor is almost entirely covered with sphagnum moss. Regeneration is sparse and patchy (fig. 7b). A few forbs, and a very few patches of *Vaccinium* spp. are present.

The 221 live trees per acre in the overstory consist mainly of small- to large-diameter hemlock and redcedar and small grand fir (table 2). One large live white pine and one Douglas-fir are on the plot. Hemlock is present in all diameter classes, and redcedar in all but the largest class (fig. 7c). Large-diameter hemlock and redcedar are about 200 years old on this plot. They evidently developed concurrently about 50 to 60 years after the white pine. A large number of hemlock and somewhat fewer redcedar trees in the two smallest diameter classes create a bimodal diameter distribution for these species. Some of these trees are from a younger cohort successfully moving from the understory into the midcanopy. Others are suppressed trees as old as the larger canopy trees. The grand fir (about 75 years of age) is from a more recent wave of recruitment. Trees in the smaller diameter classes lend the stand a multistoried character, as indicated by the distribution of canopy coverage (fig. 7d).

Most of the 161 dead trees per acre are standing. They include a few medium to large white pine, small to medium hemlock, and small redcedar (table 2). Mortality patterns are quite similar to Canyon Creek plot 1, the other closed-canopy plot. Besides the death of most seral species, the greatest concentration of mortality is in the smallest size classes of hemlock and redcedar (fig. 7e). Suppression mortality is an important factor on this plot.

Regeneration density (1,752 trees/acre) is greater than on the closed-canopy plot in Canyon Creek, but still much lower than on the gappy- and open-canopied plots. Hemlock is 77 percent of the regeneration, with 12 percent redcedar, and smaller proportions of Pacific yew and grand fir (table 2). The vast majority of regeneration trees are in the 1-foot height class (fig. 7f). The smallest trees are concentrated around decomposed nurse logs and rootmounds, and in patches beneath canopy gaps. A few well-established grand fir and hemlock saplings 6 to 12 feet in height are likely to dominate the next generation of trees.

DISCUSSION

"Old growth" is not easily defined. At the very simplest, the term has been used to describe stands with large, old trees. It usually evokes a mental image of an all-aged stand where shade-tolerant species are replacing seral species, with multiple canopy layers, snags and down dead trees, living trees with decadent tops, and patches of regeneration (Franklin and others 1981). This is a reasonably accurate description of the northern Idaho study sites. Hemlock/redcedar stands in early mature stages generally obtain full canopy coverage, nearly excluding understory species. In later successional stages they can form old-growth stands with an open, parklike nature. Understory development normally is reinitiated in these later stages.

In general, the study plots reflect these different successional stages. The closed-canopy plots (Canyon Creek plot 1 and Tepee Creek plot 2) are successionally (though not necessarily chronologically) the "youngest" of the old-growth stands. Both plots appear to be in the late phase of "stem exclusion" or early phase of "understory reinitiation," according to Oliver's conceptual model of stand development (1981). The sites are heavily shaded and have a

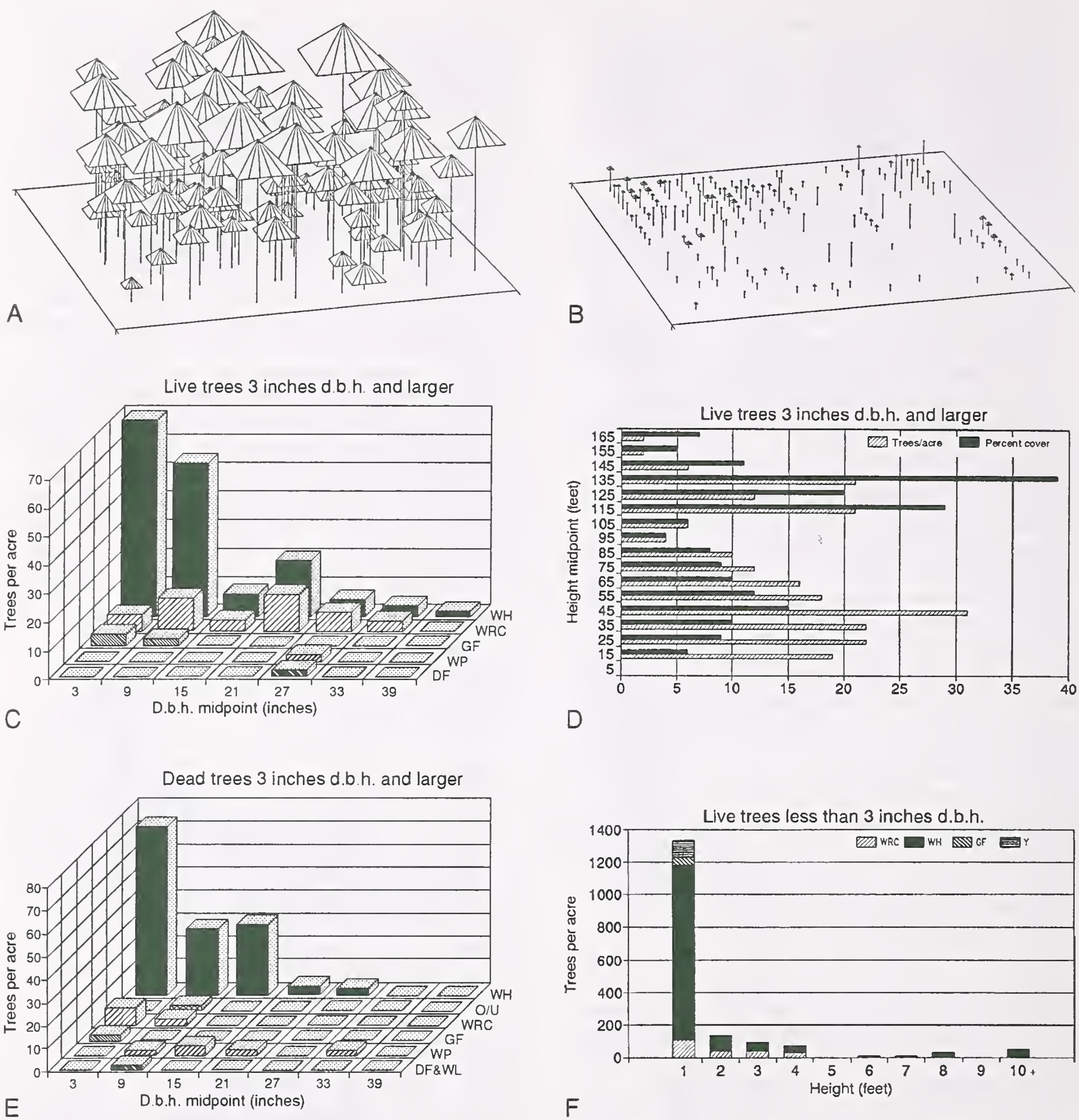

Figure 7—Tree distributions on Tepee Creek plot 2 (closed canopy). See figure 2 for species abbreviations.

generally depauperate understory, with very little conifer regeneration, or herbaceous plants, or shrubs.

The gappy-canopied plots (Montford Creek plot 1 and Tepee Creek plot 1) represent transitional stages between late "understory reinitiation" and early "old-growth" (Oliver 1981). The original canopy is beginning to break up enough to allow significant regeneration. Generally, the canopy on these sites is multistoried, quite broken and patchy, with a range of small to large distinct canopy gaps. Regeneration is patchy and concentrated around canopy gaps.

The open-canopied plots (Canyon Creek plot 2 and Montford Creek plot 2) have a decadent canopy of large, old trees below which regeneration is developing quite successfully. The character of these stands is striking, with towering high-crowned scattered hemlocks, a very broken canopy, and lots of light in the understory. Regeneration is abundant. On one plot (Tepee Creek plot 2), a distinct second canopy of advanced regeneration is distributed uniformly across the site. On the other plot (Montford Creek plot 2), regeneration is concentrated in patches influenced by heavy maple, yew, and shrub competition.

As these forests have approached old age, mortality of the seral species (and later, of shade-tolerant individuals) has created openings in the canopy, facilitating the gradual dominance of shade-tolerant climax species. The patchiness of the understory is distinctive in these forests. It appears to be related to the heterogeneous distribution of light and other microenvironmental factors resulting from canopy openings. On closed-canopy plots, mortality concentrated in trees below the main canopy has not created regeneration opportunities. Regeneration density is an order of magnitude lower on these closed plots compared with the gappy or open plots (table 2).

Hemlock and redcedar comprise most of the reproduction on the plots. Where they occur together, hemlock is normally more competitive than redcedar (Daubenmire and Daubenmire 1968). Both are prolific seed producers, have seedlings that can persist in deep shade, and can release when light levels are increased (Parker 1986; Tucker and Emmingham 1977). Regeneration only needs to occur sporadically for the site to continue to be dominated by either species. Canopy gaps facilitate their release and successful development. Almost no shade-intolerant individuals are present in the regeneration on any study plot. This is strong evidence that white pine, larch, and Douglas-fir will be excluded from these sites in the absence of a stand-replacing disturbance.

Light is not the only, nor may it be the most important, factor in determining species composition of natural regeneration beneath old-growth canopies. Soil properties, especially pH, are strongly influenced by litterfall from mature hemlock and redcedar trees (Turner and Franz 1985). In turn, soil properties probably influence the success of hemlock and redcedar seedlings in different ways. More research is needed on the relationship of the two species and soil properties, and on the implications of this relationship for management in the hemlock/redcedar zone.

The task of developing management strategies to maintain old-growth forests, and ensure a continuing supply falls partly to research. If we increase our understanding of regeneration and interactions with the existing canopy, we may develop new, creative management guidelines for mature forests, where traditional even-aged harvest systems and regeneration methods are not suitable. Silvicultural options that include multiple-entry removals using concepts of residual diameter distributions, cultivation of advanced regeneration or underplanting tolerant conifers, and retention of snags and large debris to leave a "biological legacy" can be applied to try to perpetuate (or create) certain forests in old-growth conditions (Franklin and others 1986; Hansen and others 1991; Klinka and others 1990; Lorimer 1989; Newton and Cole 1987; Old-Growth Definition Task Group 1986). The more we understand how such stands regenerate and perpetuate themselves in an old-growth condition, the better we can incorporate appropriate natural regeneration techniques into management activities. For example, single tree-selection will allow regeneration and release of shade-tolerant trees, but larger group selection cuts are needed to introduce shade-intolerant species.

Finally, six large permanent plots have been established in protected sites. These plots are part of the inventory of permanent research plots maintained by the Intermountain Research Station and will be scheduled for remeasurement in 10 years. The resulting information will provide valuable baseline growth and mortality information for these old-growth forests.

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Six permanent study plots were established in old-growth stands of western hemlock/ western redcedar in the Canyon Creek, Montford Creek, and Tepee Creek Research Natural Areas in northern Idaho. Species composition and size distribution are summarized for live canopy trees, dead trees, and regeneration trees on each plot. Comparisons of structural characteristics between plots are made on the basis of successional age as measured by relative canopy openness. These data establish a baseline for natural development of old stands in sampled habitat types.

KEYWORDS: old growth, canopy, regeneration, plant succession, natural regeneration

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